REPORT OF THE COMMITTEE ON THEATER ENGINEERING*

Summary.—*An account of the work of the several sub-committees of the Theater Engineering Committee during the past year. The report of the Sub-Committee on Projection Practice embodies a comprehensive power survey in theaters throughout the country, and interim reports of the Working Committees on Tools and Tolerances, and on Fire Hazards. The report on screen brightness and illumination meters includes an analysis and organization of the entire practical system of photometric nomenclature and conversions.*

The report of the Sub-Committees on Theater Design refers to the projected glossary of terms used in the theater design and discusses the question of staggered seating in theaters. Consideration is given also the proposal to use green instead of red lights for auditorium exit signs.

Prior to 1930 relatively limited attention was paid by the Society to the practical problems of projection, aside from the usual activities of the Standards Committee in establishing dimensional specifications for equipment. In 1930, however, the Board of Governors decided that it was timely, because of the growing complexity and importance of the art of projection, to establish a committee whose function would be to investigate the problems of practical projection, to establish recommendations for the design and layout of projection rooms, and to formulate recommended operating and maintenance procedures. Such a committee was formed under the name of the "Projection Practice Committee," and it has been active continuously, and in a valuable and important way, for ten years. For the past several years consideration has been given by various members of the Board of Governors of the Society, informally and from time to time, to the possibility of enlarging the scope of the Projection Practice Committee so as to include all phases of theater design, aside from the commercial, as well as problems of projection *per se*.

Some phases of theater design had already been considered by the Projection Practice Committee, but it was felt that there were other phases that should be analyzed, and that the Projection Practice

* Presented at the 1940 Fall Meeting at Hollywood, Calif.; received October 10, 1940.

Committee, as then constituted, was not fully equipped to handle all such matters.

At the meeting of the Board of Governors on July 13, 1939, it was resolved that the Projection Practice Committee be superseded as of December 31, 1939, by a new committee, to be known as the "Theater Engineering Committee" and which would take over and broaden the work then being conducted by the Projection Practice Committee.

This was accordingly done, and in January, 1940, a chairman was appointed and the personnel of the Committee established. This personnel is given in a later section of this report. The duty of the Theater Engineering Committee is to gather technical and operating facts, digest and analyze these facts, consider equipment and operating methods, and issue from time to time reports covering matters of interest to the exhibitor, architect, and engineer. The activities of the Committee are conducted mainly through two sub-committees. One of these, the Sub-Committee on Projection Practice, continues substantially the activities of the previous Projection Practice Committee, including the study of problems relating specifically to motion picture film, projection equipment, projection room design and construction, motion picture screens, sound-reproducing equipment, and loud speakers, together with the related measurement and test methods.

The Sub-Committee on Theater Design is concerned with those features of design and construction of theaters contributing to better picture quality and entertainment value, including seating arrangements, floor contours, wall construction (from both the acoustic and visual viewpoints), and numerous additional related matters.

Meetings of the two sub-committees are held separately, each month, and each sub-committee has established for itself a number of "Working Committees" to attend to the various details of the work. Widely representative membership has been selected for both sub-committees and it is expected that steady progress in the development and improvement of theater design and operation will result over a period of years from the activities of the Theater Engineering Committee.

The personnels of the main committee and the two sub-committees are as follows:

THEATER ENGINEERING COMMITTEE

ALFRED N. GOLDSMITH, *Chairman*

Projection Practice Sub-Committee

H. RUBIN, *Chairman*

T. C. BARROWS
H. D. BEHR
K. BRENKERT
F. E. CAHILL, JR.
C. C. DASH
A. S. DICKINSON
J. K. ELDERKIN
J. FRANK, JR.
R. R. FRENCH
E. R. GEIB
M. GESSIN
A. GOODMAN
H. GRIFFIN
S. HARRIS
J. HOPKINS
C. HORSTMAN
L. B. ISAAC
P. J. LARSEN
J. H. LITTENBERG
M. HOBART
E. R. MORIN
J. R. PRATER
F. H. RICHARDSON
J. J. SEFING
V. A. WELMAN
R. O. WALKER
H. E. WHITE
A. T. WILLIAMS

Theater Design Sub-Committee

B. SCHLANGER, *Chairman*

F. W. ALEXA
J. S. CLARKE, JR.
D. EBERSON
J. FRANK, JR.
M. M. HARE
M. HOBERT
S. HARRIS
C. HORSTMAN
K. C. MORRICAL
E. R. MORIN
I. L. NIXON
C. C. POTWIN
A. L. POWELL
A. L. RAVEN
R. F. ROSS
E. S. SEELEY
J. J. SEFING

REPORT OF THE PROJECTION PRACTICE SUB-COMMITTEE

Power Survey

A questionnaire has been formulated to secure a cross-section of data in relation to (*1*) the trend in current consumption for the various electrical units used in theaters throughout the country; (2) the total cost of electric current; (*3*) energy consumption charges; and (*4*) the average proportions of power used for projection, air-conditioning, lighting, *etc.*

The Committee felt that about 1600 of these survey reports, representing about 10 per cent of the total number of theaters, should be received before attempting to summarize the data obtained. Up to the present time, 1300 reports have been received. However, some of them will have to be discarded because of incompleteness of the data submitted. The present report on the data received is therefore preliminary, to indicate principally the nature and purposes of the study being conducted by the Working Committee on the Power Survey.

It is expected that a final and complete report will be available at the next Convention of the Society in the Spring of 1941.

Very few industries operate with as great a variety of electrical equipment as is found in motion picture theaters. Motors as small as

$^{1}/_{20}$ hp are used on ticket machines and motors 300 hp in size have been found operating compressors on refrigeration equipment. Projection rectifiers and motor-generator sets in general use range from 3 to 40 hp. Besides power required for incandescent and neon lighting, and radios, additional power is needed for motors used for many purposes, such as for projection, sound reproduction, ventilation, refrigeration, pumps, oil-burners, rewinders, grinders, ticket machines, flashers, vacuum cleaners, *etc.*

A study of the forms of power available in various sections of the country has been undertaken (Table I), with the result that it has been found that 60-cycle alternating current is the standard for power distribution and is almost universally available. More than 95 per cent of the distributed a-c power for general use is at a frequency of 60 cycles. This does not include railways and certain large industries using 25-cycle supply. A frequency of 50 cycles is used in all of southern California and in the vicinity of Los Angeles, although not in the city proper where the 50-cycle supply has recently been converted to 60 cycles. There are no plans to change to 60 cycles generally in southern California. Forty-cycle power is used to a limited extent in New England, principally in Rumford Falls, Me., and in Palmer Falls and Plattsburg, N. Y. Plattsburg has also 60-cycle power. In and around Buffalo the 25-cycle supply for general distribution has been largely supplemented with 60-cycle power, although the heavy industries remain on 25 cycles. Niagara Falls has switched from 25 to 60 cycles.

A small area in Central New York State, north of Oneonta, is supplied with 25-cycle power, and also Keokuk and Ft. Madison, Iowa, and nearby communities. Around Geneva and Auburn, N. Y., the frequency is $62^{1}/_{2}$ cycles.

Certain of the larger cities have direct current available in certain districts, but in practically all these districts 60-cycle alternating current is also available. These cities are Cleveland, Chicago, New York, Baltimore, Detroit, Boston, Kansas City (Mo.), New Orleans, Washington (D. C.), St. Louis, and Cincinnati.

There has been a tendency on the part of the large power companies to standardize on 120 volts for lighting and 208 volts for power service. The power companies in many cases meter the power supply on the primary or high-voltage side of the transformers, whether company-owned or theater-owned transformers are used, this procedure resulting in an increased number of kwh charged to the theater. A lack of uniformity exists in the rates in various localities even where one power company operates in adjacent areas.

The data received indicate that power rates range from a minimum of 1.14¢ to 6¢ per kwh, up to 6000 kwh a month; 1.13¢ to 4.06¢ up to 15,000 kwh a month; and from 0.99¢ to 2.49¢ up to 30,000 kwh a month. The committee has compiled a chart covering 57 widely separated cities of populations greater than 50,000, showing the power available in terms of voltage, phase, and frequency, and the minimum and maximum costs per kwh, in the three power-consumption brackets, namely, 6000, 15,000, and 30,000 kwh per month. This chart clearly shows the lack of uniformity in rate structure and accounts for some of the complaints of theater owners on excessive power bills.

Thirty widely separated cities were selected to determine minimum and maximum costs of operating lighting and power equipment. This analysis shows that charges to a theater having a load of 6 kw, using 750 kwh per month for lighting only, ranged from a minimum of $22 for Los Angeles, Calif., to a maximum of $56 for Miami, Fla. A load of 12 kw (lighting), with a consumption of 1500 kwh, led to charges from $41 to $105 for the same cities. The analysis disclosed also the fact that for a 12-kw load, at 1500 kwh a month, the cost is $22 for Seattle, Wash., and $67 for Boston, Mass. A 30-kw load, at 6000 kwh a month, costs $68 in Seattle and $219 in Chicago. A 75-kw load, at 15,000 kwh a month, costs $178 in Los Angeles and $360 in Denver. A 75-kw load, at 30,000 kwh a month, costs $295 in Los Angeles and $537 in Jacksonville, Fla.

The questionnaire charts distributed widely throughout the industry will show the number and proportion in use of arcs, according to types and power sources, the average seating capacities of theaters, picture sizes, and many other factors. Charts are being prepared showing the proportion of power used and the corresponding costs, for the various theater functions, including projection, lighting, refrigeration, *etc.*, and graphs are being prepared showing the average total costs of power in different localities. It is believed that these graphs will enable exhibitors to determine whether or not they are operating with average electrical efficiency and economy. The survey indicates that an amount of the order of 20 million dollars a year is expended for electric power to operate theater equipment, for a power consumption ranging from 600 to 800 million kwh yearly, and for a connected capacity exceeding 600,000 kw.

TABLE I

Power Available in Various Cities

	Voltage	Phase	Cycles	30 Kw 6000 Kwh Min.	30 Kw 6000 Kwh Max.	75 Kw 15,000 Kwh Min.	75 Kw 15,000 Kwh Max.	75 Kw 30,000 Kwh Min.	75 Kw 30,000 Kwh Max.
Albany, N. Y.	120–208	1–3	60	2.35		1.69	2.11	1.09	1.46
Atlanta, Ga.	120–208	1–3	60	2.01	3.44	1.79	2.05	1.45	1.57
Atlantic City, N. J.	120–208	1–3	60	3.03	3.06	2.46		1.70	
Baltimore, Md.	120–208	1–3	60	2.85		2.45		1.79	
Boston, Mass.	120–208	1–3	60	2.95	2.98	2.40	2.59	1.56	1.64
Brockton, Mass.	120–208	1–3	60	2.64		1.95	2.21	1.36	1.49
Buffalo, N. Y.	120–208	1–3	25 & 60	1.51		1.05	1.69	.80	1.05
Canton, Ohio	117¼–204	1–3	60	2.97	3.00	2.22		1.50	
Chicago, Ill.	120–208	1–3	60	3.34		2.05	2.53	1.52	1.76
Cincinnati, Ohio	120–208	1–3	60	2.77	2.96	2.25	2.42	1.52	1.74
Columbus, Ohio	120–208	1–3	60	2.02	2.22	1.81	2.12	1.31	2.06
Dallas, Texas	115–230	1–3	60	2.69		2.21		1.57	
Dayton, Ohio	114–199	1–3	60	2.58		2.27		1.40	1.75
Denver, Col.	120–208	1–3	60	2.60		2.40		1.63	
Detroit, Mich.	120–208	1–3	60	2.85	2.99	2.58		1.66	
	120–240	1–3	60						
Evanston, Ill.	115–200	1–3	60	3.01	4.24	2.47	2.72	1.71	1.83
Fort Wayne, Ind.	120–208	1–3	60	1.75		1.59	2.14	1.40	1.55
Fort Worth, Tex.	120–208	1–3	60	3.00		2.41		1.70	
Harrisburg, Pa.	120–208	1–3	60	2.79	3.53	2.21	0.47	1.47	1.49
Houston, Texas	122–211	1–3	60	2.13		2.17	2.19	1.44	1.46
Indianapolis, Ind.	120–208	1–3	60	1.83	3.06	1.90		1.33	
Knoxville, Tenn.	115–199	1–3	60	1.30		1.30		.95	
Lincoln, Neb.	120–208	1–3	60	1.46	2.24	2.04	1.97		
Long Beach, Calif.	120–208	1–3	50–60	2.03	2.82	1.51	2.65	1.22	1.70
Louisville, Ky.	120–208	1.3	60	2.51	2.53	1.97		1.36	
Lynn, Mass.	120–208	1–3	60	2.63		1.76		1.04	
Madison, Wis.	120–208	1–3	60	1.65	2.24	1.56	2.16	1.16	1.62
Memphis, Tenn.	120–208	1–3	60	1.73		1.13		1.57	
Miami, Florida	115–230	1–3	60	2.27	4.03	2.75		2.05	
Milwaukee, Wis.	120–208	1–3	60	2.10	3.22	1.79	2.54	1.44	1.90
Minneapolis, Minn.	120–208	1–3	60	2.55	2.88	1.91	2.47	1.46	1.84
Mount Vernon, N. Y.	120–208	1–3	60	3.87	4.81	2.94	4.06	2.11	2.55
New Orleans, La.	120–208	1–3	60	2.68		2.06	2.40	1.48	1.65
New York, Bronx	122–211	1–3	60	5.16		2.52	3.46	1.97	2.39
Brooklyn	122–211	1–3	60	4.86		2.57	3.46	1.67	2.39
Manhattan	122–211	1–3	60	5.16		3.17	3.46	2.09	2.39
Queens	122–211	1–3	60	3.44	5.16	2.13	3.46	1.64	2.39
				2.97	6.00	1.99		1.48	
Richmond	110–220	1–3	60	3.17	3.39	2.24		1.70	
Newark, N. J.	120–208	1–3	60	3.12		2.47	3.05	1.57	2.00
Oak Park, Ill.	115–199	1–3	60	3.61	4.24	2.47	2.72	1.71	1.83
Oklahoma City, Okla.	120–208	1–3	60	2.17	4.00	1.98		1.21	1.51
Philadelphia, Pa.	115–230	1–2	60	2.84		1.90	2.01	1.25	1.30
Pittsburgh, Pa.	115–199	1–3	60	2.37		1.96		1.23	
Portland, Oregon	123–213	1–3	60	1.14	2.37	1.53	1.87	1.16	1.38
Providence, R. I.	120–208	1–3	60	1.74	2.17	1.77	1.80	1.22	1.30
Richmond, Virginia	120–208	1–3	60	2.37		1.65	2.22	1.33	1.73
Rochester, N. Y.	120–208	1–3	25 & 60	2.74	2.99	1.97	2.64	1.27	1.61
St. Paul, Minn.	120–208	1–3	60	2.68	2.88	2.07	2.77	1.59	1.86
San Antonio, Tex.	120–208	1–3	60	2.06	2.14	1.63	1.86	1.09	1.22
San Francisco, Cal.	122–211	1–2–3	60	1.47	1.93	1.54		1.19	
Scranton, Pa.	120–208	1–3	60	2.44	2.97	1.75	2.33	1.27	1.61
Seattle, Wash.	120–208	1–3	60	1.14	2.05	1.42	1.77	.99	1.11
		1–3	60						

TABLE 1 (*Continued*)

	Voltage	Phase	Cycles	30 Kw 6000 Kwh Min.	Max.	75 Kw 15,000 Kwh Min.	Max.	75 Kw 30,000 Kwh Min.	Max.
South Bend, Ind.	120–208	1–3	60	2.68	2.97	2.21		1.57	
Spokane, Wash.	120–208	1–3	60	1.33	1.87	1.77		1.23	
Springfield, Mass.	120–208	1–3	60	2.00	2.91	2.51	3.83	2.67	1.67
Toledo, Ohio	120–208	1–3	25 & 60	3.120	4.34	2.30	2.79	1.55	1.84
Washington, D. C.	120–208	1–3	60	2.00	2.29	1.61	2.16	1.32	1.62
Wichita, Kansas	115–199	1–3	60	2.54		2.24	2.69	1.41	1.59
Wilmington, Del.	120–208	1–3	60	2.49	3.09	2.13	2.47	1.50	2.31
Worcester, Mass.	120–208	1–3	60	2.58	3.10	1.85	3.36	1.36	2.49
Yonkers, N. Y.	120–208	1–3	60	3.67	4.27	2.52	3.49	1.83	2.23

Tools, Tolerances, and Safety Factors

For many years it has been the viewpoint of the Projection Practice Sub-Committee that a study should be made of projector mechanisms in use in theaters to determine the best operating adjustments for various tension devices, the limits of permissible or tolerable wear of mechanical parts, and methods of determining these factors. The corresponding measurements require that consideration be given to the development of inexpensive tools as an aid in making such determinations in the theater. After a careful study of the projector and sound-head mechanisms, the Working Committee on Tools and Tolerances picked as its first objective the determination of the most suitable gate tension consistent with tolerable picture jump.

In order to coördinate the work with any data available from other sources, various projector manufacturers were consulted as to what standards of gate tension were employed during manufacture of the equipment. The replies disclosed the fact that only one manufacturer set a definite numerical standard for picture-gate tension, the others depending upon experienced mechanics to make adjustments through observation of actual operation of the machine.

For experimental studies, two types of spring tension gauges were used. Results obtained by the form that pulls a piece of film through the gate were not sufficiently consistent. The other form, which measured the pressure of the tension shoe, gave more nearly uniform readings; however, it can be used only with the gate removed from the projectors.

During the past few months, tests have been made on projectors in theaters throughout the New York area and it was found that the tension shoe pressure varied considerably from theater to theater, and between projectors in the same theater. At the present time attempts are being made to determine the minimum pressure that can be used while yet keeping the picture jump within allowable limits.

At the same time a study will be made to determine how picture-gate tension affects wearing of the intermittent sprocket teeth and the sprocket-holes in the film.

Fire Hazards

Last year the report on fire hazards comprised an extensive proposed revision of the "Regulations" of the National Board of Fire Underwriters for nitrocellulose motion picture film, as recommended by the National Fire Protection Association.

The Committee is pleased to report that these recommendations were adopted by the NBFU and the NFPA almost in their entirety and were published on July 1, 1939, as NBFU Pamphlet No. 40.

Last spring an invitation was received by the Committee from the National Fire Protection Association to delegate a person to address the meeting of the fire marshals on the opening day of the NFPA Convention, May 7, 1940, at Atlantic City, N. J. Mr. Sylvan Harris was appointed to attend the Convention and to make the address. The valued coöperation of the State of Connecticut was received, through the official appointment of Inspector E. A. Morin to attend the Convention and present a special exhibit of a model projection room and other displays to the delegates. The address included a general review of the efforts of the motion picture industry to improve the design and operation of motion picture projection rooms, and particularly from the standpoint of fire prevention and fire control. Attention was called to the chaos that existed in such matters a number of years ago when the Society first began to issue its recommended projection room plans. The recent general improvement in conditions was described, but attention was called to the fact that even at this late date numerous inconsistencies and conflicts exist throughout the country in the fire regulations and building codes of the various states and municipalities. The building codes for motion picture theaters require much revision and standardization, and a plea was made that steps be taken to correct the situation. An invitation was extended to the fire marshals, the NFPA, the NBFU, and various other organizations to coöperate with the SMPE in presenting to the fire prevention authorities all over the country the need for greater uniformity and logical consistency in the establishment of fire regulations.

Subsequently to the NFPA Convention, and as a result of the exhibition of the model projection room, requests for further information concerning the work of the State of Connecticut were received from the Department of Public Safety of the City of Rochester, N. Y., and from the Provincial Fire Commissioner's Office of the Province of Quebec, Canada.

Some items not covered in the previously mentioned revision of the NFPA "Regulations" are still under consideration, and the Working Committee on Fire Hazards intends to have material on these matters ready for a report at the next Convention.

There are also under consideration the possible ways of acquiring reliable and complete information as to the causes of film fires in projection rooms and also means for analyzing the data as obtained.

Screen Brightness and Illumination Meters

During the past year this Working Committee has given consideration to the subject of meters for measuring light reflected from the screens of motion picture theaters. It is hoped to report definitely at the Spring Meeting of the Society on the type or types of meters found to be most suitable for this purpose.

The subject of photometric nomenclature and conversions is of great interest to the Sub-Committee on Projection Practice, as well as to other committees of the Society. The following analysis of the subject by Mr. Sylvan Harris, originally intended for publication as an individual paper, has been included in this report as useful and informative material.

PHOTOMETRIC NOMENCLATURE AND CONVERSIONS

Photometric nomenclature and conversions between various units are involved in the work of the Projection Practice Sub-Committee, as well as the Standards Committee, and to a considerable extent at present. Particularly is this the case with respect to the establishment of suitable standards of illumination for motion picture screens. The multiplicity of photometric terms and units has often led to difficulty and, in some cases, even to serious confusion, especially in attempting to interpret literature on photometric subjects and in reconciling measurements of various groups of investigators. As far as is known, no publication is available in which any attempt has been made to organize the entire system of photometric nomenclature into a logical and systematic whole. The purpose of the present work is to fill this need.

Nomenclature

First, there are presented the fundamental relations upon which the photometric nomenclature depends:

Luminous Source.—The starting point of photometric measurements is the "candle." A standard or unit candle is said to have an *intensity* of one "candle-power."

Luminous Flux.—The *quantity of visible radiation* emitted by a source is stated in terms of the *lumen.* The lumen, as will be shown below, is $1/4\pi$ of the total flux emitted by a point-source radiating luminous energy uniformly in all directions.

Illumination, or Flux-Density.—The terms "illumination" and "flux-density" are synonymous. Let a point-source of light emit luminous energy uniformly in all directions. Then the flux-density on the surface of a sphere of radius r circumscribed about the point-source is

$$E = \frac{\varphi}{4\pi r^2} \quad (1)$$

where E is the flux-density and φ is the total flux. The dimensions of E are thus units of flux per unit of area. The various units are given in Table I. It is to be carefully noted that when several terms occur in the same block of the table, these terms are synonymous and equivalent.

TABLE I

Illumination

Where φ is in	and r is in	E is in
lumens	cm	lumens/sq-cm cm-candles phots
lumens	m	lumens/sq-m meter-candles lux
lumens	inch	lumens/sq-in inch-candles
lumens	ft	lumens/sq-ft ft-candles

Intensity of the Source.—For the purpose of comparing the intensities of sources, it is convenient to refer the flux-density to a sphere of unit radius. Thus, in equation *1* let $r = 1$ and substitute I for E, which gives

$$I = \frac{\varphi}{4\pi} \qquad (2)$$

Intensity is thus the flux-density (or illumination) referred to unit distance from the source. The area of a unit sphere is the same as the number of steradians of solid-angle (ω) about the point-source, so the dimensions of I are units of flux/steradian. This unit is also called "candle-power," or simply the "candle."

TABLE II

Intensity

Where φ is in	and ω is in	I is in
lumens	sterad	lumens/sterad candles

Brightness, or Intrinsic Brilliancy.—Brightness is defined as the luminous intensity of the source per unit of projected area of the source; or, letting b = brightness and A = area of the source:

$$b = \frac{I}{A} \qquad (3)$$

The source whose brightness is being calculated may be either a primary source (or an original radiator) or a secondary source (a reflector). The dimensions of brightness b are thus units of flux per steradian per unit of area, or candles per unit of area. The various units are given in Table III.

TABLE III

Brightness (In Terms of Intensity)

Where I is in	and A is in	b is in
candles lumens/sterad	sq-cm	candles/sq-cm lumens/sterad/sq-cm stilb
candles lumens/sterad	sq-m	candles/sq-m lumens/sterad/sq-m
candles lumens/sterad	sq-in	candles/sq-in lumens/sterad/sq-in
candles lumens/sterad	sq-ft	candles/sq-ft lumens/sterad/sq-ft

In equation *3* and Table III, brightness has been defined in terms of intensity. It may be expressed also in terms of flux. The brightness of a luminous surface emitting one lumen per sq-cm is known as the *lambert*. The dimensions of this unit are units of flux per unit

TABLE IV

Brightness (In Terms of Flux)

Where φ is in	and A is in	b is in
lumens	sq-cm	lumens/sq-cm lamberts
lumens	sq-m	lumens/sq-m meter-lamberts apostilb
lumens	sq-in	lumens/sq-in inch-lamberts
lumens	sq-ft	lumens/sq-ft ft-lamberts

of area, the same as the dimensions of illumination units, and an analogous set of terms has come into use. Thus, if the illumination of a surface is 1 ft-candle (= 1 lumen/sq-ft) and the reflectance of the surface is 100 per cent, the reflected flux-density will be 1 lumen/-sq-ft and the brightness 1 ft-lambert. The various terms are given in Table IV.

Conversions

Since the terms in Table I, III, and IV are specified in various units of area (sq-cm, sq-m, sq-in, sq-ft), conversions may be made from one term to another *within a given table*. The "internal" conversions of Tables I, III, and IV are given in Tables V, VI, and VII. The conversion factors are given both in operational and numerical forms.

In using the tables, the factors shown are employed when passing to the right and upward. When passing from the top downward and then to the left, the reciprocals are used, thus:

$$\text{ft-candles} = 10.764 \times \text{meter-candles}$$

$$\text{meter-candles} = \frac{1}{10.764} \times \text{ft-candles}$$

In addition to the "internal" conversions, an "external" conversion is possible between Tables III and IV, since brightness is expressed in two ways—in terms of intensity and in terms of flux.

TABLE V

Illumination

	lumens/sq-cm cm-candles phots	lumens/sq-m meter-candles luces*	lumens/sq-in inch-candles	lumens/sq-ft ft-candles
lumens/sq-cm cm-candles phots	1	$(100)^2$ = 10,000	$(2.54)^2$ = 6.4516	$(2.54 \times 12)^2$ = 929.030
lumens/sq-m meter-candles luces*	$\left(\frac{1}{100}\right)^2$ = 0.0001	1	$\left(\frac{2.54}{100}\right)^2$ = 0.000645	$\left(\frac{2.54 \times 12}{100}\right)^2$ = 0.092903
lumens/sq-in inch-candles	$\left(\frac{1}{2.54}\right)^2$ = 0.15500	$\left(\frac{100}{2.54}\right)^2$ = 1550.00	1	$(12)^2$ = 144
lumens/sq-ft ft-candles	$\left(\frac{1}{2.54 \times 12}\right)^2$ = 0.0010764	$\left(\frac{100}{2.54 \times 12}\right)^2$ = 10.764	$\left(\frac{1}{12}\right)^2$ = 0.006944	1

* Plural of "lux."

TABLE VI

Brightness (In Terms of Intensity)

	candles/sq-cm lumens/sterad/ sq-cm stilb	candles/sq-m lumens/sterad/ sq-m	candles/sq-in lumens/sterad/ sq-in	candles/sq-ft lumens/sterad/ sq-ft
candles/sq-cm lumens/sterad/sq-cm stilb	1	$(100)^2$ = 10,000	$(2.54)^2$ = 6.4516	$(2.54 \times 12)^2$ = 929.030
candles/sq-m lumens/sterad/sq-m	$\left(\frac{1}{100}\right)^2$ = 0.0001	1	$\left(\frac{2.54}{100}\right)^2$ = 0.000645	$\left(\frac{2.54 \times 12}{100}\right)^2$ = 0.092903
candles/sq-in lumens/sterad/sq-in	$\left(\frac{1}{2.54}\right)^2$ = 0.15500	$\left(\frac{100}{2.54}\right)^2$ = 1550.00	1	$(12)^2$ = 144
candles/sq-ft lumens/sterad/sq-ft	$\left(\frac{1}{2.54 \times 12}\right)^2$ = 0.0010764	$\left(\frac{100}{2.54 \times 12}\right)^2$ = 10.764	$\left(\frac{1}{12}\right)^2$ = 0.006944	1

TABLE VII

Brightness (In Terms of Flux)

	lumens/sq-cm lamberts	lumens/sq-m meter-lamberts apostilbs	lumens/sq-in inch-lamberts	lumens/sq-ft ft-lamberts
lumens/sq-cm lamberts	1	$(100)^2$ = 10,000	$(2.54)^2$ = 6.4516	$(2.54 \times 12)^2$ = 929.030
lumens/sq-m meter-lamberts apostilbs	$\left(\frac{1}{100}\right)^2$ = 0.0001	1	$\left(\frac{2.54}{100}\right)^2$ = 0.000645	$\left(\frac{2.54 \times 12}{100}\right)^2$ = 0.092903
lumens/sq-in inch-lamberts	$\left(\frac{1}{2.54}\right)^2$ = 0.15500	$\left(\frac{100}{2.54}\right)^2$ = 1550.00	1	$(12)^2$ = 14.4
lumens/sq-ft ft-lamberts	$\left(\frac{1}{2.54 \times 12}\right)^2$ = 0.0010764	$\left(\frac{100}{2.54 \times 12}\right)^2$ = 10.764	$\left(\frac{1}{12}\right)^2$ = 0.006944	1

The flux emitted by a flat element of diffusing surface is shown in textbooks on photometry to be $\varphi = \pi I$. Substituting in equation *3*, the brightness, in intensity units, is*

$$b = \frac{1}{\pi}\left(\frac{\varphi}{A}\right) \tag{4}$$

If $\varphi/A = 1$ flux unit of brightness (*e. g.*, 1 lambert), $b = 1/\pi$ intensity unit (*e. g.*, 1 candle/sq-cm), or

$$\text{intensity units} = \pi \times \text{flux units} \tag{5}$$

Conversion between Tables III and IV therefore involves π. The various "external" conversion factors are given in Table VIII.

TABLE VIII

Brightness

	lumens/sq-cm lamberts	lumens/sq-m meter-lamberts apostilbs	lumens/sq-in inch-lamberts	lumens/sq-ft ft-lamberts
candles/sq-cm lumens/sterad/sq-cm stilbs	π $= 3.1416$	$\pi(100)^2$ $= 31416$	$\pi(2.54)^2$ $= 20.268$	$\pi(2.54 \times 12)^2$ $= 2918.6$
candles/sq-m lumens/sterad/sq-m	$\pi\left(\frac{1}{100}\right)^2$ $= 0.00031416$	π $= 3.1416$	$\pi\left(\frac{2.54}{100}\right)^2$ $= 0.0020268$	$\pi\left(\frac{2.54 \times 12}{100}\right)^2$ $= 0.29186$
candles/sq-in lumens/sterad/sq-in	$\pi\left(\frac{1}{2.54}\right)^2$ $= 0.48695$	$\pi\left(\frac{100}{2.54}\right)^2$ $= 4869.5$	π $= 3.1416$	$\pi(12)^2$ $= 452.39$
candles/sq-ft lumens/sterad/sq-ft	$\pi\left(\frac{1}{2.54 \times 12}\right)^2$ $= 0.003381$	$\pi\left(\frac{100}{2.54 \times 12}\right)^2$ $= 33.81$	$\pi\left(\frac{1}{12}\right)^2$ $= 0.021817$	π $= 3.1416$

Reflection Factor.—Reflection factor is the ratio of the light-flux emitted by a secondary source (*i. e.*, a reflector) to the light-flux incident upon the secondary source from the primary source.

* This formula is based upon the assumption that the reflecting surface is completely diffusing; *i. e.*, the reflection follows Lambert's law.

Let φ_i be the incident flux and φ_r the reflected flux. The reflection factor is then

$$f = \frac{\varphi_r}{\varphi_i}$$

Since $\varphi_r = \pi b A$ (eq. *4*) and $\varphi_i = EA$ (equation *1*),

$$f = \frac{\pi b}{E}$$

The intensity units of brightness are the basic units, and must be used in all formulas involving b. If the brightness is given in flux units they must be converted to intensity units, thus:

$$f = \frac{\pi \times \text{intensity units}}{\text{illumination}} \quad e.\ g.,\ f = \frac{\pi \times \text{candles/sq-ft}}{\text{ft-candles}}$$

$$= \frac{\pi \times \left(\frac{1}{\pi} \times \text{flux units}\right)}{\text{illumination}} \qquad = \frac{\pi \times \left(\frac{1}{\pi} \times \text{ft-lamberts}\right)}{\text{ft-candles}}$$

$$= \frac{\text{flux units}}{\text{illumination}} \qquad = \frac{\text{ft-lamberts}}{\text{ft-candles}}$$

REPORT OF SUB-COMMITTEE ON THEATER DESIGN

Among the activities of the Sub-Committee on Theater Design is a project that is sufficiently advanced for presentation at the Spring Convention, 1941. This project involves preparing a glossary or system of nomenclature of terms for use in connection with the subject of theater design. Lack of consistent and clear nomenclature has handicapped the work of this Sub-Committee, and also has led to the confusion existing in the field because of certain inappropriate terms as well as multiplicity of terms sometimes used in reference to the various items of consideration in theater design.

All phases of theater design are covered in the compilation of this glossary. Included are the acoustic, seating, viewing, traffic, projection, auditorium and auditorium lighting, and ventilating phases. Approximately 250 terms have been compiled with the aid of engineers and architects in the various fields of endeavor connected with this work. The Sub-Committee is now occupied in formulating the proper definition for these terms. In many instances certain terms and definition will be taken from sources already established as standard.

This Sub-Committee has also made a study of the use of staggered seating in motion picture theaters. Staggered seating exists in all theaters in which the seating width of the auditorium is greater than fourteen seats. This is so because of the magnitude of the angle subtended to the screen from positions on either side of the centrally located fourteen seats, and also because the seats are initially placed directly behind one another in lines parallel to the center-line of the auditorium. In these cases, however, the stagger effect does not exist in the central bank of chairs when the chairs are placed directly behind one another in lines parallel to the center-line of the auditorium.

It was noted that the view of the screen was unobstructed from the side seats, which had the stagger effect, whereas serious obstruction of the view of the screen was evident in the same theater on the same floor slope from the centrally located seats. It has been found generally that the usual floor slope in the motion picture theater auditorium was sufficient for the side seating sections having the stagger effect, but not sufficient for the central seating section. It has also been found that if the floor slope were to be increased to make it possible to have unobstructed vision of the screen from the central section of seats, the slope would be excessive and dangerous from the hazard standpoint and would create serious difficulties in the functional design of the theater. In many cases the screen has been placed at an undesirable height above the floor to overcome obstruction difficulties.

It is therefore proposed that where floor slopes become too great for unobstructed viewing of the screen or where the screen would otherwise be placed too high, the central section of seats be placed so that a stagger effect is produced. This means that every alternate row of seats in the central section would have only one seat less than the row behind, or before, and would result in a total loss of seats amounting to only about $1^1/_2$ per cent of the total.

It is also proposed that in existing motion picture theaters having inadequate floor slopes, the central section of seats be reset according to a stagger system. It is not necessary to stagger the seats in a certain number of the rows nearest the screen because the amount of stagger does not leave sufficient space between the heads of the preceding spectators to permit a view of the entire picture from those rows. Since only a nominal floor slope is necessary under those seats to achieve unobstructed vision, the seats in this area can be arranged on a non-stagger plan.

Attention is directed to the desirability of a requirement relative to staggered seating laid down by the State of Connecticut. This regulation permits staggered seating provided that the aisle line remains unbroken. This unbroken line is made possible by the use of end-of-row chairs of different width so arranged as to maintain the stagger effect.

Immediate consideration has also been given to the recommendation for the use of green lights behind the exit signs in the auditorium instead of the usual red lights. The green light is favored because it is now a popular conception that a green light denotes safety and in traffic regulation or control means a signal to go ahead. A green light of the proper tone is also more restful and less disturbing to the eyes while viewing the picture. The American Standards Association describes the spectrum of an acceptable green glass as containing yellow, green, blue, and violet, with only a trace of red and orange. This hue is known as "admiralty green" and has a bluish tint when observed by daylight. The ASA may make some slight revision regarding this color in the near future, however, and the use of this particular hue, therefore, should be tested prior to its adoption under the lighting conditions found in the average motion picture auditorium.

A series of surveys of physical and operating conditions in motion picture theaters has been started and is being continued with the aim of obtaining data upon which motion picture theater design may be based.